Optimal design for hybrid vehicles with switching dynamics

Massimo De Mauri, Joris Gillis, Goele Pipeleers and Jan Swevers
Department of Mechanical Engineering, KU Leuven, *Member of Flanders Make*, Belgium
Email: massimo.demauri@kuleuven.be

1 Intro

Hybridization of powertrains represents a promising approach in designing fuel efficient vehicles. The effectiveness of hybridization arises from the possibility to combine the features of different propulsion technologies in order to improve the overall tank-to-wheel energy transformation efficiency.

In comparison to traditional ones, hybrid powertrains require the designer to consider a wider variety of components allowing for a great number of distinct topologies. Moreover, once a topology candidate is chosen, the designer must select appropriate values for a set of parameters, such as: battery capacity, engine/electro-motors size, available reduction ratios, etc. When the optimization of performance is concerned, the design task can be regarded as the solution of an optimal design problem.

It is possible to cast the optimal design problem as an optimal control problem by obtaining a differential model of the target vehicle and simulate its behavior while tracking a suitable speed reference cycle. Control problems arising from the automotive field often involve non-linear dynamics and discrete variables, since clutches and stepped gearboxes are commonly incorporated in road vehicles. Hence, the class of problems the designer runs into falls in the category of mixed-integer non-linear optimal control problems.

Bearing in mind the previous considerations, we will present a solution schema for mixed integer non-linear optimal control problems based on a multiple shooting time discretization structure and a variable time transformation reformulation.

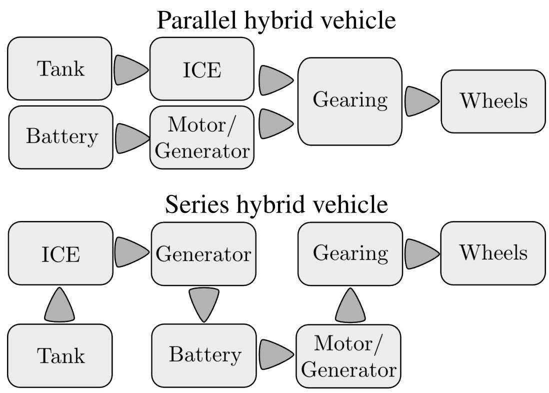
2 Approach

The reformulation employed, inspired by the work of Sager [2, 3], is based on a convexification of the problem with respect to the discrete variables. Convexification, coupled with an iterative time grid refinition process and a rounding strategy, enables the setting up of an initial suboptimal switching structure by means of sequential solutions of a continuous problem relaxation. Then, for each possible value assignment of the discrete variables, a distinct continuous differential-algebraic model is defined. At this point, it is possible to set up a new multi stage continuous problem in which the system is, initially, supposed to pass through all the stages of the given switching structure. The duration of each stage is controlled by a continuous parameter that constitutes a degree of freedom for the optimization. The duration of a stage might eventually shrink to zero causing the system to skip suboptimal stages. This feature eliminates the need for the a priori knowledge of the optimal switching structure.

The result of the reformulation is a grid-dependent optimal and feasible solution for the original problem. Therefore, the problem was effectively transformed into a continuous non-linear optimal control problem.

3 Results

The results of the presented approach will be shown with the help of two case studies: the first one deals with a parallel hybrid vehicle and the second one with a series hybrid vehicle. The comparison with a classical branch and bound solution schema will be presented as well.



References

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[2] Gerdts et al., Mixed-Integer DAE Optimal Control Problems : Necessary Conditions and Bounds, 2012.

[3] Sager et al, Direct methods with maximal lower bound for mixed-integer optimal control problems, 2009.

[4] https://github.com/casadi/casadi/wiki (symbolics and algorithmic differentiation).

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